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14. ABSTRACT

The Alfred Gessow Rotorcraft Center has considerable experience in the design, fabrication and testing of rotor models because of its dedicated unparalleled rotorcraft-related experimental facilities.

The objective of this grant was to acquire key equipment needed to augment the facilities for precision data acquisition required to generate a comprehensive set of measurements of the blade surface pressures, pitch link

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## Sub Contractors (DD882)

## Inventions (DD882)

## Scientific Progress

## Technology Transfer

**DURIP INSTRUMENTATION PROPOSAL**

# Instrumentation for "Fabrication and Testing of High-Speed Single-Rotor and Compound-Rotor Systems"

**Inderjit Chopra, University of Maryland**

**Final Report to Army Research Office (ARO)**

**Grant No. W911NF-14-1-0-0400**

**Period: 04/14/2014 to 01/13/2016**
**Final Report Date: January 2016**

**Dept. of Aerospace Engineering**
**Alfred Gessow Rotorcraft Center**
**University of Maryland**

**Inderjit Chopra**
**chopra@umd.edu**

# Fabrication and Testing of High-Speed Single-Rotor and Compound-Rotor Systems

**Inderjit Chopra (chopra@umd.edu) Principal Investigator**
**Director Alfred Gessow Rotorcraft Center**
**Department of Aerospace Engineering**
**University of Maryland, College Park, MD 20742**

**Final Report to ARO**
**Grant No. W911NF-14-1-0400**
**Period: 04/14/14 to 01/13/2016**
**Final Report Date: February 2016**

**Abstract**

The final report of an ARO sponsored DURIP grant, entitled "Fabrication and Testing of High- Speed Single-Rotor and Compound-Rotor Systems," is presented. Dr. Matthew J. Munson, U.S. Army Research Office, is the Technical Monitor of this grant.

The Alfred Gessow Rotorcraft Center has considerable experience in the design, fabrication and testing of rotor models because of its dedicated unparalleled rotorcraft-related experimental facilities. These facilities include: 8.5 ft. x11 ft. Glenn L. Martin Wind Tunnel, two fully instrumented rotor rigs respectively for Mach-scale and Froude-scale models, 10-ft diameter vacuum chamber, hover tower, anechoic chamber, rotor fabrication facility and microsystem laboratory.

The objective of this grant was to acquire key equipment needed to augment the facilities for precision data acquisition required to generate a comprehensive set of measurements of the blade surface pressures, pitch link loads, hub loads, rotor wakes and performance of high-speed single-rotor and compound-rotor systems to support the development of the next-generation of rotorcraft, such as envisioned in Joint Multi-Role (JMR) rotorcraft program. These data are crucial to validate advanced CFD tools as well as gain improved understanding of the fundamental physics in high advance ratio flight conditions. A variety of Mach-scale rotor configurations were tested on our hover stand and in the Glenn L. Martin wind tunnel, covering a range of flight conditions including full-disk retreating-side reversal ($\mu \approx 1.5$). Many of these activities have already taken place and many more are in progress at the University of Maryland under different rotary-wing programs sponsored by Army, and these instrumentation have helped in overcoming some deficiencies in previous precision data acquisition and data processing capabilities.

The acquired instrumentations include: precision ultra-thin pressure transducers, miniature load cells, 150-lines slip ring, rotating torque sensors, brushless DC motors and controllers, miniature 6-component transducers, low capacity torque sensor, 3D Printer, miniature milling machine, ETG Eye Tracking System, closed loop digital control valve, data acquisition system and VICON Motion Capturing Cameras.

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The report outlines some of the key features of the purchased equipment and describes some of the applications where they have been used.

# Fabrication and Testing of High-Speed Single-Rotor and Compound-Rotor Systems

**Final Report to ARO**
**Grant No. W911NF-14-1-0400**
**Period: 04/14/14 to 01/13/2016**
**Final Report Date: January 2016**

**Table of Content:**

# Fabrication and Testing of High-Speed Single-Rotor and Compound-Rotor Systems

## INTRODUCTION

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The objective of this grant was to acquire key equipment needed to augment the facilities for precision data acquisition required to generate a comprehensive set of measurements of the blade surface pressures, pitch link loads, hub loads, rotor wakes and performance of high-speed single-rotor and compound-rotor systems to support the development of the next-generation of rotorcraft, such as envisioned in the Joint Multi-Role (JMR) rotorcraft program. These data are crucial to validate advanced CFD tools as well as gain improved understanding of the fundamental physics in high advance ratio flight conditions. A variety of Mach-scale rotor configurations are being tested on our hover stand and in the Glenn L. Martin wind tunnel, covering a range of flight conditions including full-disk retreating-side reversal ($\mu \approx 2$). Many of these activities are already in progress at the University of Maryland under different rotary-wing programs sponsored by the US Army, and these instrumentations are helping in overcoming some deficiencies in previous precision data acquisition and data processing.

The research program at the Alfred Gessow Rotorcraft Center (AGRC) is built around four interrelated thrust areas, namely: rotorcraft dynamics and aeroelasticity; aerodynamics and acoustics; flight dynamics and controls; and composite and smart structures. The research tasks are equally balanced between theoretical, computational and experimental components. Because of the intense and dedicated efforts of students, faculty, and staff, all experimental facilities are fully functioning and used routinely as an integral part of graduate research and educational activities [1-2]. Not only these facilities represent the result of a large, multi-year financial investment, but also perhaps more importantly, they represent the result of a multi-year investment in intellectual resources. Many of these facilities are frequently used by the rotorcraft industry. The objective of the instrumentations procured under this DURIP was to expand the extent and quality of our experimental research output, and thereby, upgrade some of the key facilities at the AGRC.

Slowed rotors – traditionally associated with autogyros and gyroplanes – have long been recognized as one potential solution for high-speed helicopters (200-300 knots). During the 1950s–70s, there were several significant programs that led to the development of high-speed helicopters with thrust and lift compounding [6-8]. The key technology barriers common to all were extremely high fuel consumption due to high advancing side drag and large reverse flow, complexities associated with RPM reduction, large blade motions during RPM reduction, and unexplained but catastrophic aeroelastic instabilities of rigid rotors (Cheyenne). None of these helicopters entered regular production. Today, the CarterCopter gyroplane [9, 10] is the only aircraft to have demonstrated a rotor advance ratio of 1.0 in flight in 2005. With the advancement of materials, controls, and propulsion/drivetrain technologies (15-20% direct variation in RPM possible with same nominal specific fuel consumption and more dramatic reduction promised with variable drivetrain), slowed rotors have once again begun to emerge as a viable solution to high-speed, high-efficiency helicopters of the future (along with tilt-rotors and lift-offset coaxial compounds) [11-14]. The intent is the fundamental understanding of such rotors, using both analysis and experiment; at the very high-advance ratio reverse flow conditions they are envisioned to operate in ($\mu \approx 1.5$-$2.0$ and beyond).

Compared to conventional helicopters, there are only a handful of limited experimental measurements available, which are neither sufficient for fundamental understanding of their aeromechanics nor adequate for validating high-fidelity analyses that hold promise of predicting them [15-19, 22]. The only existing data set that includes performance, pressures and loads are the recent full-scale UH-60A tests – but this data is only up to $\mu=1.0$ [23]. Model-scale tests performed recently achieve higher advance ratios (up to $\mu=2.2$), but with simple blades (symmetric NACA0012 airfoil, untwisted) in autorotation or lower advance ratios (up to $\mu=1.0$) with realistic blades (asymmetric SC1095, twisted) and powered conditions – but all focused mostly on performance measurements (additionally, flow-visualization with tufts in [20] and hub load measurements in [1]) and fall far short from being comprehensive. Similarly, discrepancies in analyses – identified both in lifting-line and CFD by a recent comprehensive study [21] have still not been systematically addressed due to the scarcity of reliable and comprehensive test data. Thus, both lack of experimental data and validated analyses can become significant technical barriers towards effective and efficient use of slowed rotors in the development of next-generation high-speed compound rotorcraft. The intent is to address these deficiencies directly.

Coaxial compound has emerged as one of the several potential solutions for high-speed rotorcraft - along with tilt-rotors and slowed-rotor compound – since the successful resolution of critical technology shortcomings associated with the earlier XH-59A demonstrator. These shortcomings – low efficiency/high fuel consumption, high empty weight fraction, high vibration, and challenges associated with reducing rotor speed –

have now been mitigated in the X2 Technology Demonstrator by innovative use of modern technologies: advanced airfoils (double-ended at root and super-critical at tip), advanced materials (Titanium to graphite-epoxy blades), active vibration control in the fixed-frame, and advanced propulsion (high efficiency pusher propeller instead of turbojet thrust. The potential of modern refined analytical tools that have matured over the last fifteen years – if brought to bear on this advanced coaxial rotor system, can bring about dramatic improvements in its capabilities. Some of the current technical challenges are: (1) reduced efficiency due to large reverse flow area in high-speed flight (80% of retreating side, at $\mu$=0.8, 20% rpm reduction, 250 knots), (2) high weight penalty due to active force generators in the fixed-frame to cancel the high vibration levels due to stiff blades, and (3) weight and drag penalty due to high root stresses as well as a large hub. Recently, the X2 Technology Demonstrator achieved a level flight speed over 250 knots, proving the basic concept of the coaxial compound configuration. However, the rotor of this aircraft was designed assuming an equivalent single rotor in conjunction with blade element momentum theory. Further development of this concept and optimization of its performance requires refined analytical tools and detailed test data. It becomes necessary to generate a benchmark set of experimental hub loads; blade surface pressures; and rotor wake velocity measurements with which the analytical tools can be validated.

Under this grant, we purchased the following instrumentations:

1. Miniature pressure transducers – Kulite and Endevco
2. Fabricast 150 lines slip ring 8256-0.0-150-60U
3. Brushless DC motors and Controllers
4. Load Sensors (RST-A10 rotating torque sensor, SLB-25 button load cell)
5. Miniature 6-component transducer
6. 3D Printer
7. Miniature Milling Machine
8. ETG Eye tracking system
9. Closed Loop Digital Control valve for hydraulic pump/motor control
10. VICON MC Cameras (MX-T20S)
11. Data Acquisition System

The report outlines some of the key features of the purchased equipment and describes some of the applications where they have been used.

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## 1. MINIATURE PRESSURE SENSOR – Kulite LQ.LE-062 and Endevco 40931

### 1.1 Description

Kulite LQ.LE-062 are miniature piezoresistive transducers used to measure static and dynamic pressure changes in fluids. It uses a semiconductor membrane which changes resistance when deformed. This output is calibrated for pressure change and can be operated in absolute, gage or differential measurement mode. The Kulite sensors have a long lead-time (6 months to 1 year) for supply. Because of this, we were forced to search for an alternate source of supply. The Endevco Meggitt miniature sensors have lead times of the order of 1 month. We have purchased these sensors and have tested them under centrifugal loading and have also calibrated them against Kulite and a standard sensor obtained from NIST.

### 1.2 Specifications

The Kulite pressure transducers are excited with 10 VDC input and are rated for 0-10 psia. The full-scale output is rated at 100 mV, with a sensitivity of 4 mV/psi and operational temperature range of $-65^0$F to $250^0$ F, with a thermal sensitivity of 1%/ $100^0$F. The Envedco pressure transducers are excited by 5 VDC input and are rated for 0-15 psia. The full-scale output is rated at 125 mV, with a sensitivity of 10 mV/psi and operational temperature range of $-67^0$ F to $212^0$ F, with a thermal sensitivity of 1%/ $100^0$100 F.

### 1.3 Applications

These miniature pressure sensors are embedded in rotor blades and used to measure pressure distribution on airfoil under different operating environments in the wind tunnel. These are extensively used in understanding the aeromechanics of Mach-scaled slowed rotor testing in Glenn L. Martin wind tunnel.

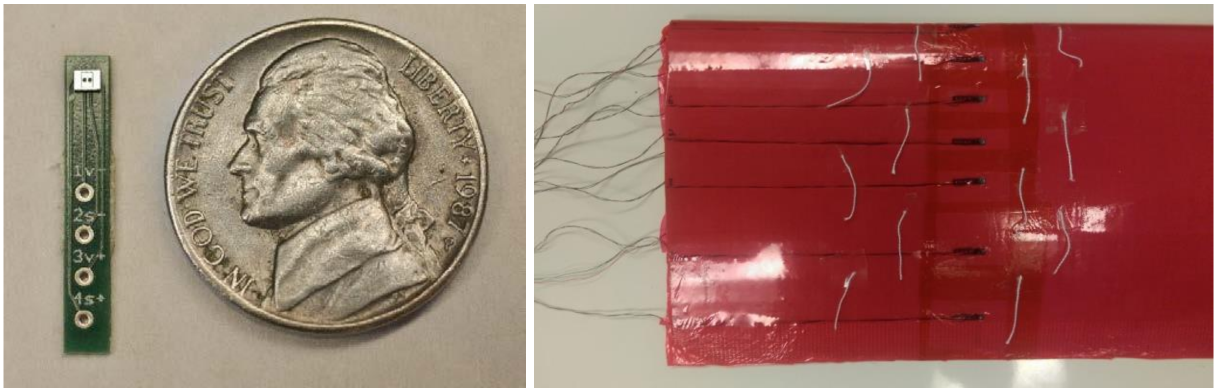

Figure 1.1 Endevco miniature transducer (left) embedded in a test specimen (right).

**1.4 Cost**

A number of Endevco sensors were purchased and mounted on a custom designed breakout board for a total cost of $ 24,271.

2. **FABRICAST 150 LINES SLIP RING 8256-0.0-150-60U**

**2.1 Description**

In rotary wing testing, it is necessary to measure loads, strains, pressures and other parameters of the rotor blades in the rotating frame using appropriate sensors. These sensors require elelctrical power and their outputs are also electrical analog signals. Sliprings are used to transfer high voltage power signals (actuation) from the fixed frame to the rotating frame and to transfer the sensor signals from the rotating frame to the fixed frame.

**2.2 Specifications**

The 150-channel slipring was custom fabricated for applications at UMD by Fabricast. It has 12 lines rated for 60 V, 5 A and remaining lines are rated at 1 A, to transmit low-voltage signals arising from strain gauges, Hall-effect sensors, accelerometers, and other sensors to the data acquisition system.

**2.3 Applications**

The slipring is required in all tests where it is necessary to record signals from the blades in the rotating frame. It is part of the hover testing rig and is used for wind tunnel testing as well.

Figure 2.1 150-lines Slipring

**2.4 Cost**

This slip ring was custom designed by Fabricast as per the specifications for a total cost of $ 28,251.

**3. BRUSHLESS DC MOTORS AND CONTROLLERS**

**3.1 Description**

As the name implies, brushless DC motors (BLDC motors) do not use brushes for commutation; instead, they are electronically commutated. BLDC motors have many

advantages over brushed DC motors and induction motors. A few of these are: better speed versus torque characteristics, high dynamic response, high efficiency, long operating life, noiseless operation, and higher speed ranges. In addition, the ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors.

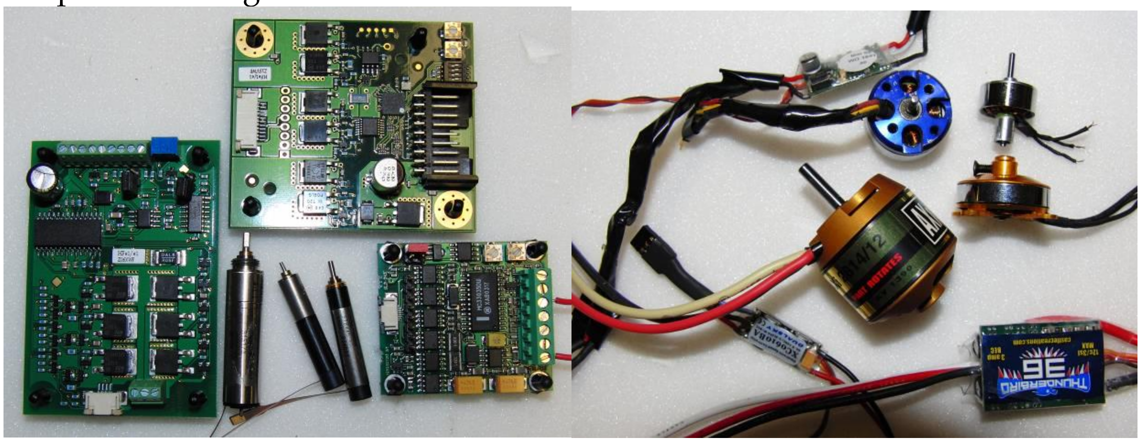

Figure 3.1 Brushless DC Motors with Controllers, inrunners (left) and outrunners (right)

### 3.2 Specifications

Several types of miniature Brushless DC motors (In-runners and out-runners) and controllers were purchased. The complete brushless motor system consists of electric motor with Hall sensors for position feedback and a nose planetary gear head. Figure 3.1 shows some brushless motors and their controllers. The Faulhaber 0620B brushless dc motor has a weight of 2.5 grams and produces a stall torque of 0.73 mNm with an input voltage of 6 volts. The Maxon EC6 Brushless DC motor has a diameter of 6 mm, and can produce a maximum torque of 0.5 mNm and maximum rated power of 1.2 watts. The Maxon EC10 Brushless DC motor with 10 mm diameter is rated at 10 mNm torque and 8 W electrical power, while Maxon EC16 Brushless DC motor has a diameter of 16 mm, and is rated for a maximum torque of 14 mNm and 40 W electrical power.

### 3.3 Applications

Figure 3.2 shows the use of miniature brushless DC motors with the associated controllers used in the Quad rotor and the rotor trailing edge flaps.

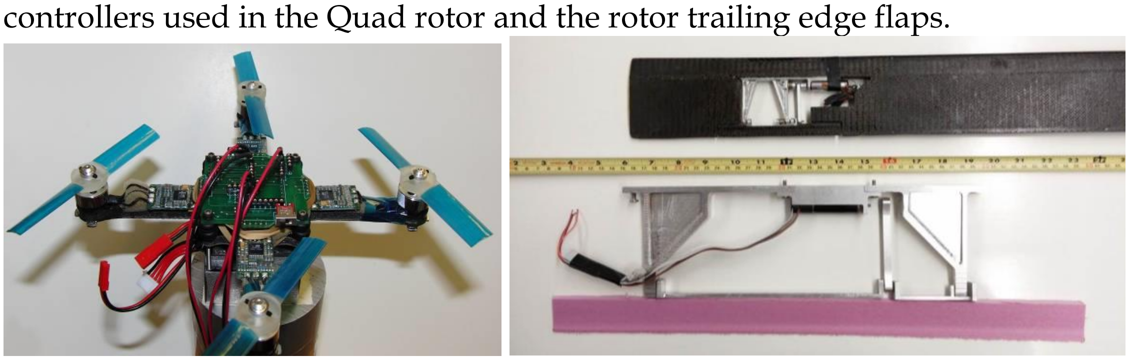

Figure 3.2 Miniature Brushless DC motors used in Quad rotor (left) and rotor trailing edge flap (right).

### 3.4 Cost

This total cost of various motors and controllers was $ 9,215.

## 4. LOAD SENSORS

### 4.1.SLB-25 BUTTON LOAD CELL

#### 4.1.1 Description

The SLB Series Subminiature load cells are used for measuring compression loads for applications where space is limited. These sensors are manufactured from heat treated 17-4ph stainless steel, and the sensing element incorporates bonded foil strain gages of the highest quality. They are sealed for protection against most industrial environments.

#### 4.1.2 Specifications

The SLB-25 load cell can measure loads up to 25 lb. Its overall dimensions are 0.375″ diameter and 0.25″ height. Its rated output is 2mV/V and it needs an excitation voltage of 5 VDC

#### 4.1.3 Applications

The SLB-25 button load cell has been used in tests of micro air vehicles for measuring the rotor thrust.

### 4.2.RST-A10 ROTATING TORQUE SENSOR

#### 4.2.1 Description

The SLB Series Subminiature load cells are used for measuring compression loads for applications where space is limited. These sensors are manufactured from heat treated 17-4ph stainless steel, and the sensing element incorporates bonded foil strain gages of the highest quality. They are sealed for protection against most industrial environments.

#### 4.2.2 Specifications

The SLB-25 load cell can measure loads up to 25 lb. Its overall dimensions are 0.375″ diameter and 0.25″ height. Its rated output is 2mV/V and it needs an excitation voltage of 5 VDC

### 4.2.3 Applications

The SLB-25 button load cell has been used in tests of micro air vehicles for measuring the rotor thrust.

## 4.3 RTS Torque Sensor

### 4.3.1. Description

In order to increase resolution for torque measurement of micro-scale rotors, the RTS series low capacity torque sensors were selected from Transducer Techniques. It enables accurate torque measurements below 50 in-oz without giving up stiffness or sensitivity to forces from other directions. They are manufactured from sensor quality aluminum and anodized for long-term durability. Bonded foil strain gages are installed assuring high reliability. The four-bolt hole pattern allows simple adaptation to specific applications.

### 4.3.2 Specifications

| | |
|---|---|
| Rated Output (R.O.): | 1.5 mV/V nominal |
| Nonlinearity: | 0.1% of R.O. |
| Hysteresis: | 0.1% of R.O |
| Nonrepeatability: | 0.05% of R.O. |
| Zero Balance: | 1.0% of R.O. |
| Compensated Temp. Range: | 60° to 160°F |
| Safe Temp. Range: | -65° to 200°F |
| Temp. Effect on Output: | 0.005% of Load/°F |
| Temp. Effect on Zero: | 0.005% of R.O./°F |
| Terminal Resistance: | 350 ohms nominal |
| Excitation Voltage: | 10 VDC |
| Safe Overload: | 150% of R.O. |

### 11.3 Applications

These were integrated onto micro rotor as well as cyclorotor test setups in order to extract the mechanical power required to drive the respective test articles. From these measurements, valuable information such as efficiency can be calculated. Shown below is a test setup of the cyclorotor installed with the RTS-50 torque sensor.

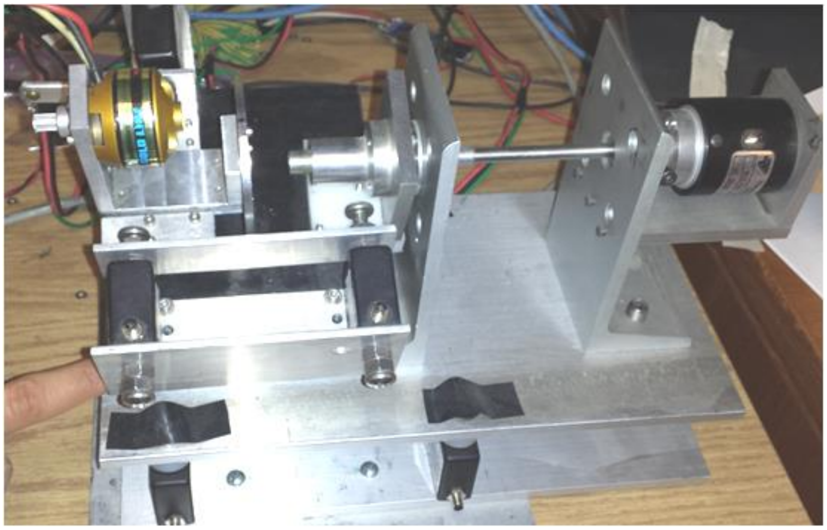

Fig. 4.1 Cyclorotor test setup installed with low capacity torque sensor

**4.4 Cost**

This total cost of various load and torque sensors was $ 916.

# 5. MINIATURE 6-COMPONENT TRANSDUCER

## 5.1 Description

The smallest commercially available 6-axis transducer in the world, the Nano17 fits into restricted spaces (Figure 7.1.1). It can resolve loads up to 0.318 gram-force. It is made from high Strength, EDM wire-cut from high yield-strength stainless steel. The output has a high signal-to-noise ratio: due to the use of silicon strain gages that provide a signal 75 times stronger than conventional foil gages.

Figure 5.1 ATI Nano-17 miniature six-component balance

## 5.2 Specifications

This transducer can measure in-plane loads of 250 N and out-of-plane loads of 480 N (both tension and compression). It can measure torques of 1.6 Nm (bending moments) and 1.8 Nm (torque). It is a compact transducer with a diameter of 17 mm, a height of 15 mm and a weight of 9.07 gm.

## 5.3 Applications

The miniature load sensor has been used in a number of applications involving micro air vehicles and flapping wing tests (Figure 5.2)

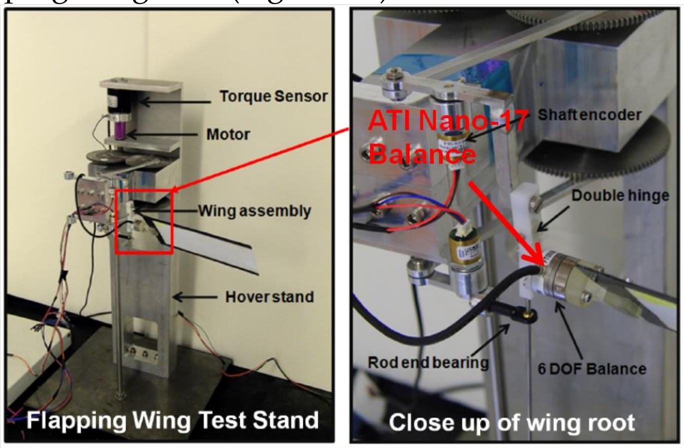


Figure 5.2 .Miniature six-component balance used on a flapping-wing test

## 5.4 Cost

This total cost of nano sensors was $ 4300.

## 6. 3D PRINTER

## 6.1. Description

The uPrint SE Plus 3D printer uses FDM Technology to build in real ABSplus thermoplastic, creating models and functional prototypes that are durable, stable and pinpoint accurate. Model and soluble support materials come on spools that are easy to load into the material bay.

## 6.2 Specifications

| | |
|---|---|
| Model Material | ABSplus in nine colors |
| Support Material | Soluble SR-30 |
| Build Size | 203 x 203 x 152 mm (8 x 8 x 6 in.) |
| Layer Thickness | .254 mm (.010 in.) |
| Power Requirements | 100–127 VAC 50/60 Hz, 15A |

## 6.3 Applications

The printer is extensively used for quick and reliable prototyping of 3D structures like various rotor designs, components of flapping wing and rotary MAVs, etc.

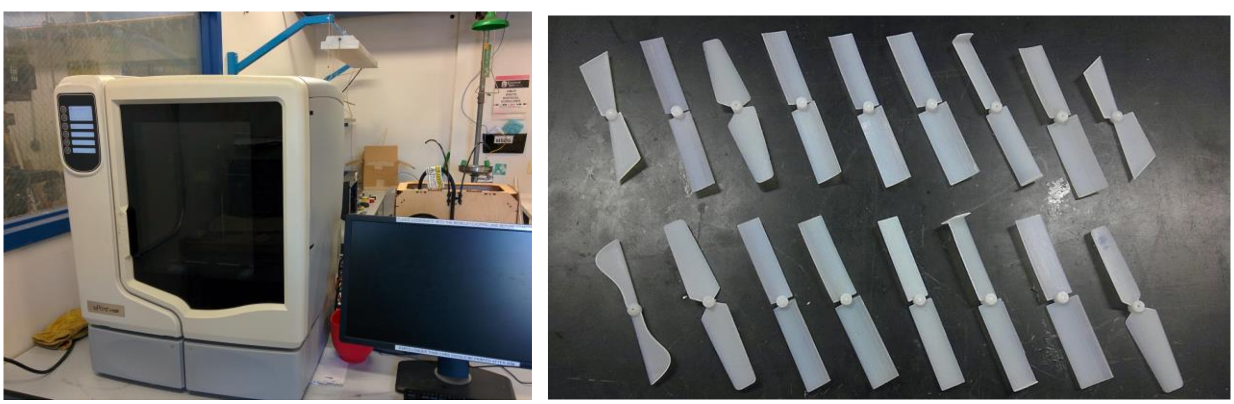

Fig. 6.1 The 3D printer (left) and an array of various parameters rotor blades (right).

## 6.4 Cost

The ABS plastic and the support material were purchased to the total cost of $2,529.

## 7. MINIATURE MILLING MACHINE

### 7.1. Description

Sherline Model 2000/2010 mill has a 14" base and a 4$^{th}$ axis rotary table. It includes laser engraved scales on the base and table and a 1/4" Jacobs drill chuck and key.

### 7.2 Specifications

| | |
|---|---|
| Max clearance, table to spindle | 9.00" (229 mm) |
| Travel, "X" Axis | 8.68" (229 mm) |
| Travel, "Y" Axis | 7.00" (178 mm) |
| Travel, "Z" Axis | 5.38" (137 mm) |
| Width overall | 15.00 (381 mm) |
| Depth overall | 22.25" (565 mm) |
| Height overall | 23.38" (568 mm) |
| Table size | 2.75" x 13.00" (70 x 330 mm) |
| Hold down provision | 2 "T" Slots |
| Spindle speed range | 70-2800 RPM continuously variable |

### 7.3 Applications

The milling machine is integral to fabricating large number of components for rotor blades and MAVs.

Fig. 13.1 Sherline milling machine with control computer

### 7.4 Cost

The complete milling machine setup cost was $ 7,183.

## 8. ETG EYE TRACKING SYSTEM

### 8.1. Description

These eye trackers are designed to record a person's natural gaze behaviour in real-time with outstanding robustness, mobility and ease of use. It supports real-time data access and full control via a wireless connection.

### 8.2 Specifications

| | |
|---|---|
| Human interface design | Non-invasive video based glasses-type eye tracker; Insertable sun glasses included |
| Glasses weight | 47g |
| Calibration | Calibrationless gaze tracking;<br>1-/3-point calibration;<br>Offline calibration correction |
| Validation | Live validation of gaze tracking quality |
| Parallax compensation | Automatic parallax compensation |
| Sampling rate | 60Hz binocular [2] |
| Gaze tracking accuracy | 0.5° over all distances (typ.) |
| Gaze tracking range | 80° horizontal, 60° vertical |
| Scene camera | Resolution: 1280x960p @24 fps;<br>960x720p @30 fps;<br>HDR (high dynamic range) mode with high sensitivity for low light |
| Scene camera field of view | Field of view: 60° horizontal, 46° vertical |

### 8.3 Applications

The eye tracker is used in experiments into the pilot response to degraded visual environments while performing tracking tasks on a computer display. It is used to correlate eye movement to characteristics to pilot performance and to help determine parameters in the Pilot Optimal Control Model.

Figure 14.1 Eye tracker output on the computer (left) and Eye tracker (right).

### 8.4 Cost

The complete Eye Tracker cost was $ 32,950.

## 9. DIGITAL CONTROL VALVE FOR HYDRAULIC MOTOR CONTROL

### 9.1. Description

The flow control valve allows to remotely modulate the amount of fluid passing to the hydraulic motor, thereby controlling the rotor speed. It is installed at the outlet of the hydraulic pump. The Bosch Rexroth FESE 25 Valve is a pilot operated 2-way proportional throttle valves for block installation for the infinitely variable control of flow. It is operated using a BRH VT-HACD-3-2X/E-I-00/000 closed loop controller, which allows set point operation. The rotor can be commanded to operate at precise RPM.

### 9.2 Specifications

This flow control valve is rated for a peak pressure of 315 bar and a maximum flow rate of 330 l/min. It is operated by a 24 V solenoid valve that is remotely modulated using a control voltage.

### 9.3 Applications

It is part of the hover test rig and is used to control the rotor RPM in hover as well as wind tunnel testing in Glenn L. Martin wind tunnel.

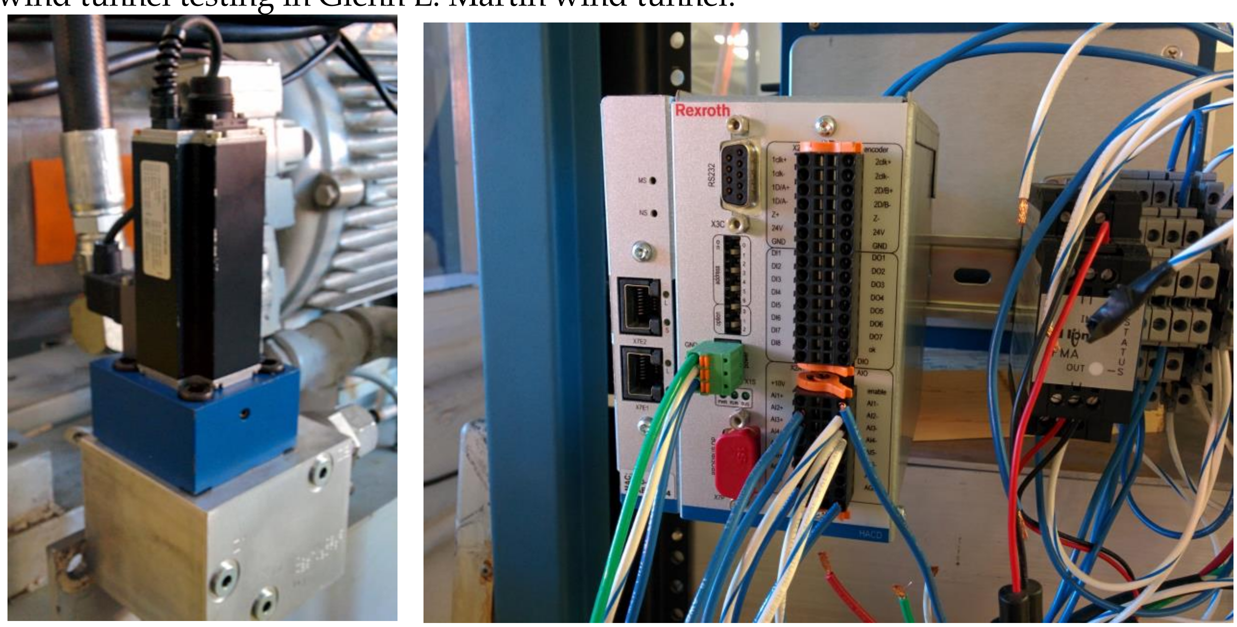


Figure 9.1 FESE 25 valve (left) and HACD closed loop controller (right).

### 9.4 Cost

The complete parts and installation cost was $ 13,993.

## 10. VICON MC CAMERAS (MX-T20S)

### 10.1. Description

The Vicon motion capture system can precisely track a large number of stereoscopic markers in a given test volume. Multiple cameras are utilized to localize the marker in three-dimensional space and the evolution of these markers with time. As the test volume increases, large number of cameras are needed to track the markers.

### 10.2 Specifications

The camera can capture at a resolution of 2 MegaPixel and is equiped with strobes to give an even spread of light across the capture volume meaning smaller markers in larger volumes are easily identified.

### 10.3 Applications

These camera systems are used for tracking flapping wing motions, blade structural deflections and MAV flight trajectory.

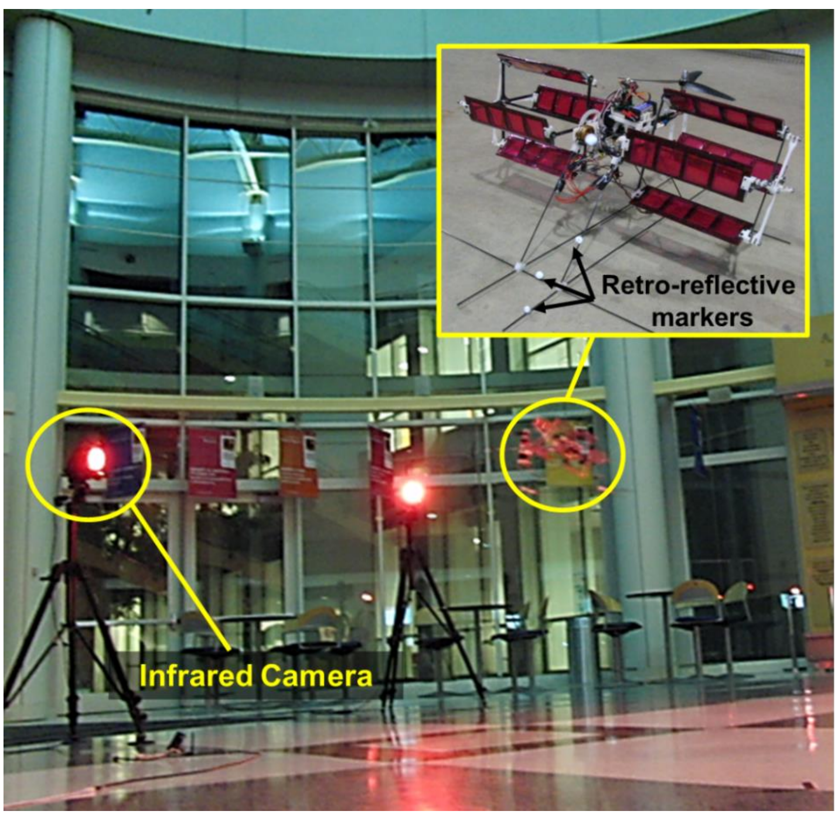


Figure 10.1 Vehicle testing using Vicon cameras

### 10.4 Cost

The four cameras set cost was $ 49,240.

## 11. Data Acquisition System

### 11.1. Description

The DGI DAQ32 is a light-weight low-power wireless data acquisition system designed for simultaneously measuring and logging 32 differential signals at rates up to 10 kHz.

### 11.2. Specification

The hardware included with the system includes:

- One DAQ32 board.
- One FAT16 formatted 2 GB Micro SD Card with the bootstrap and application binary files.
- Two 2000 mAh lithium ion polymer batteries (Sparkfun P/N PRT-08483)
- One XBee Pro wireless transceiver with wire antenna (Sparkfun P/N WRL-10421)
- One SparkFun XBee Explorer Dongle (Sparkfun P/N WRL-11697).
- One DAQ32 sensor interface breakout board.

### 11.3. Application

Effort is underway to integrate this wireless DAQ system in the rotor system to acquire and save on-board data from pressure and strain-gage type sensors at a high rate with minimum noise and interference.

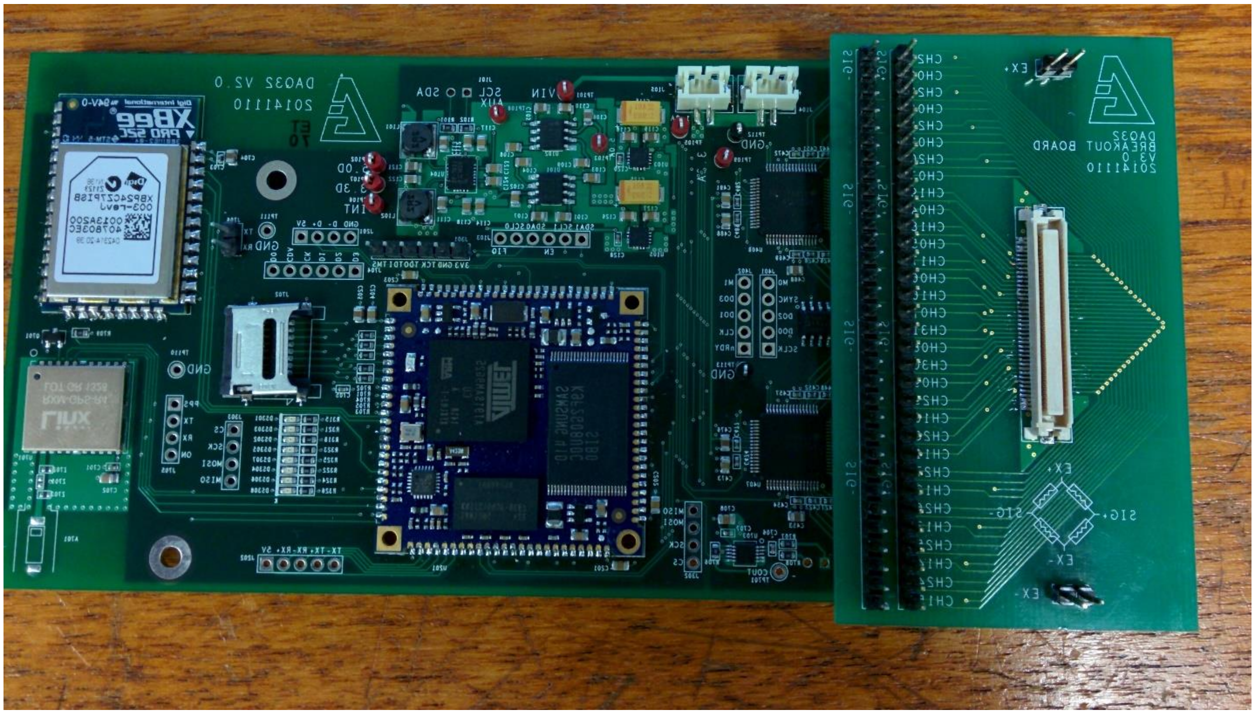

Fig. 11.1 DGI DAQ32 data acquisition board for on-board applications.

### 11.4. Cost

The total cost of this system was $5,728.